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Yatsuzuka et al.

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(54) **LINEAR COMPRESSOR**

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(51) **Int. Cl.**[7] **F04B 17/04**

(52) **U.S. Cl.** **417/417**; 417/419; 417/416; 417/488

(58) **Field of Search** 417/417, 419, 417/416, 488, 410.1

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(57) **ABSTRACT**

A linear compressor, comprises a retaining member, a fixed member supported by said retaining member and formed with a hermetically sealed compression chamber to receive a working fluid therein, a pair of pistons axially movably received in said compression chamber to assume respective compression positions, a pair of piston rods each having an outer peripheral portion and slidably movably supported by said fixed member, said piston rods respectively connected to said pistons to have said pistons axially move in said compression chamber, a plurality of magnet units mounted on each of said outer peripheral portions of said piston rods, each of said magnet units having a plurality of magnet segments each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole, a plurality of electromagnet units supported by said retaining member to be axially spaced apart from each other in predetermined relationship with said magnet units, respectively, and resilient means for resiliently urging said piston rods to cause said piston rods to assume respective neutral positions.

28 Claims, 8 Drawing Sheets

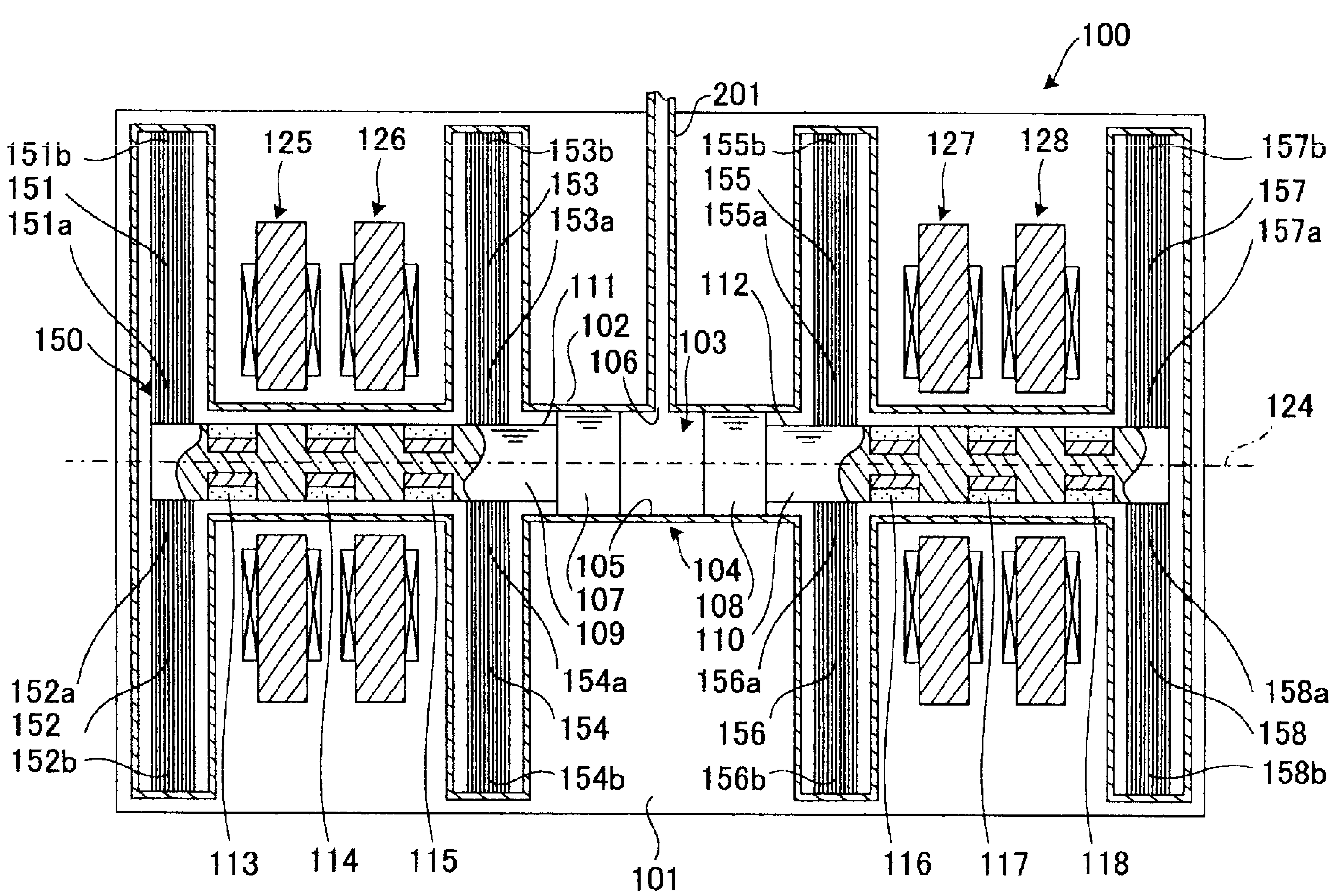


FIG. 1

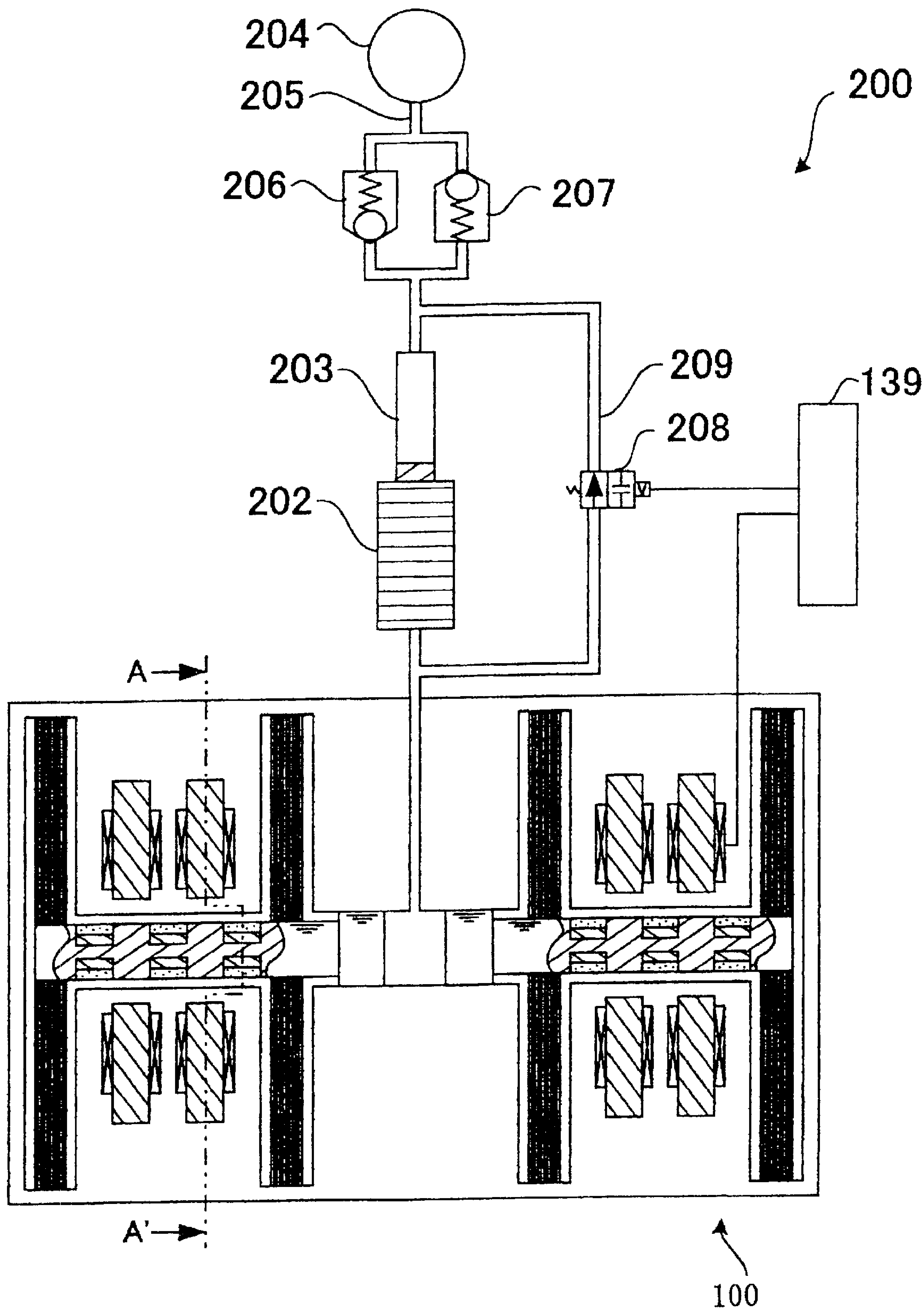
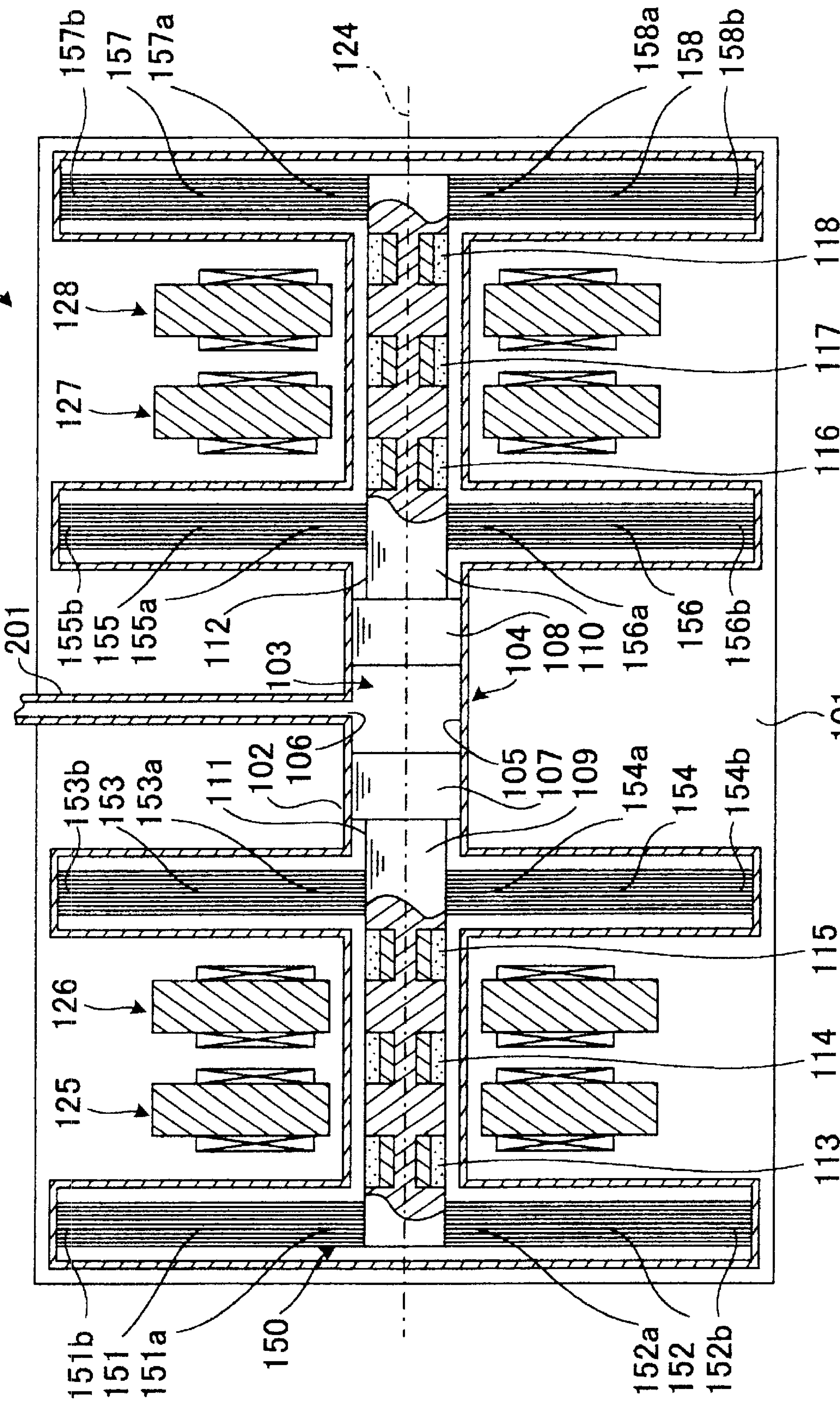


FIG. 2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158a
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158b
201

FIG. 3C

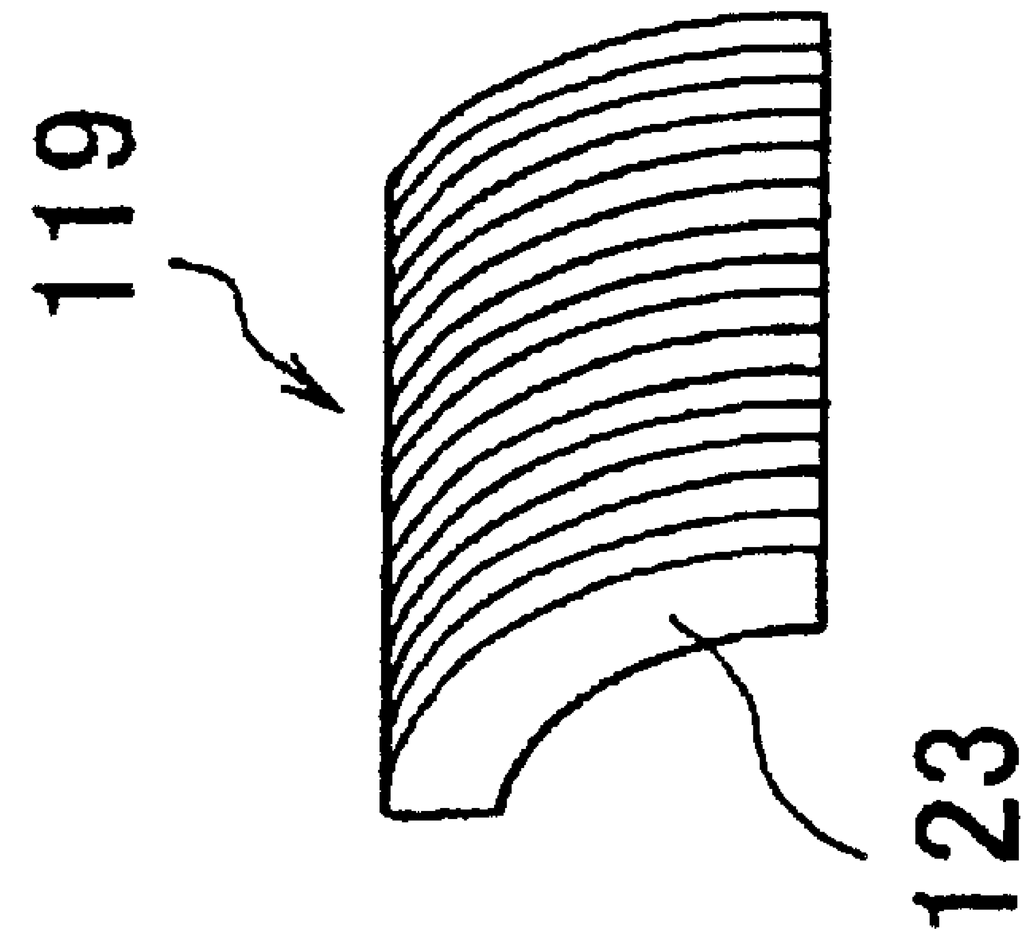


FIG. 3B

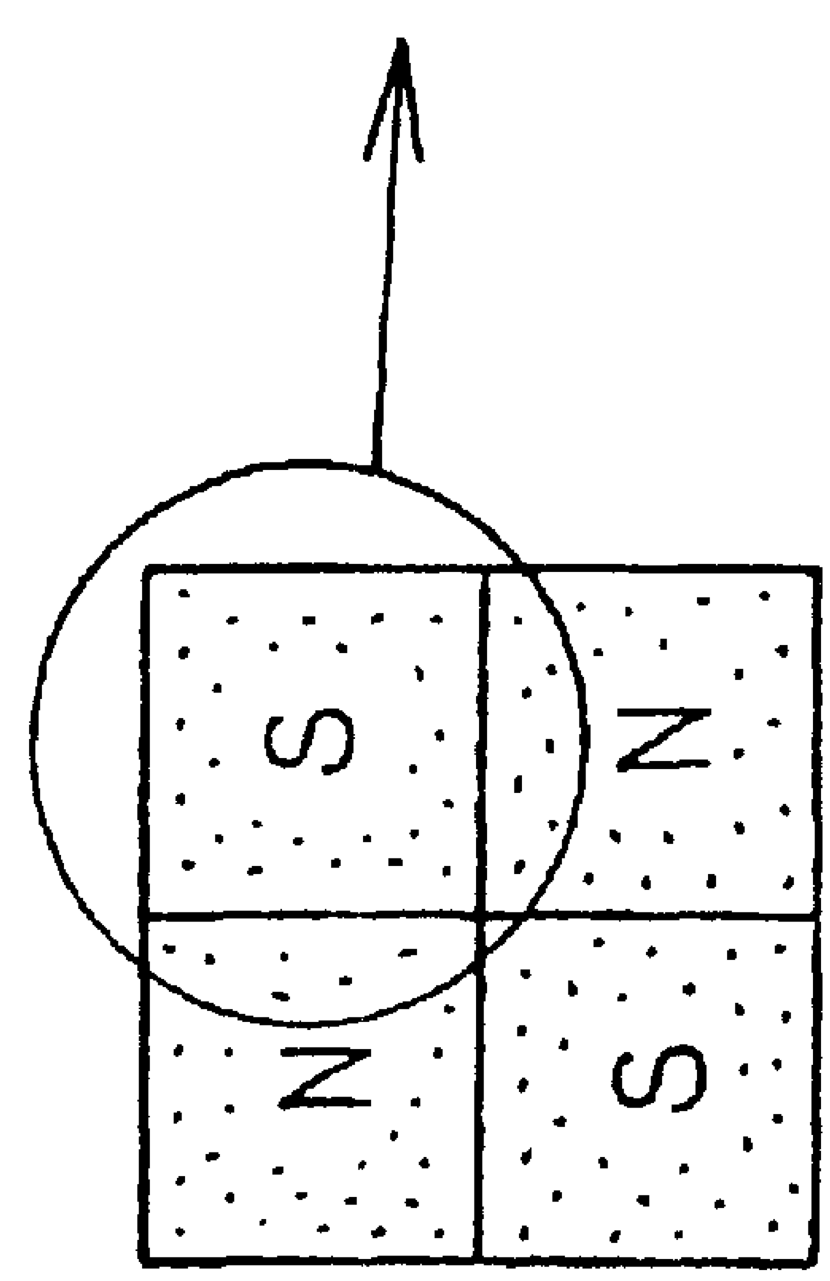


FIG. 3A

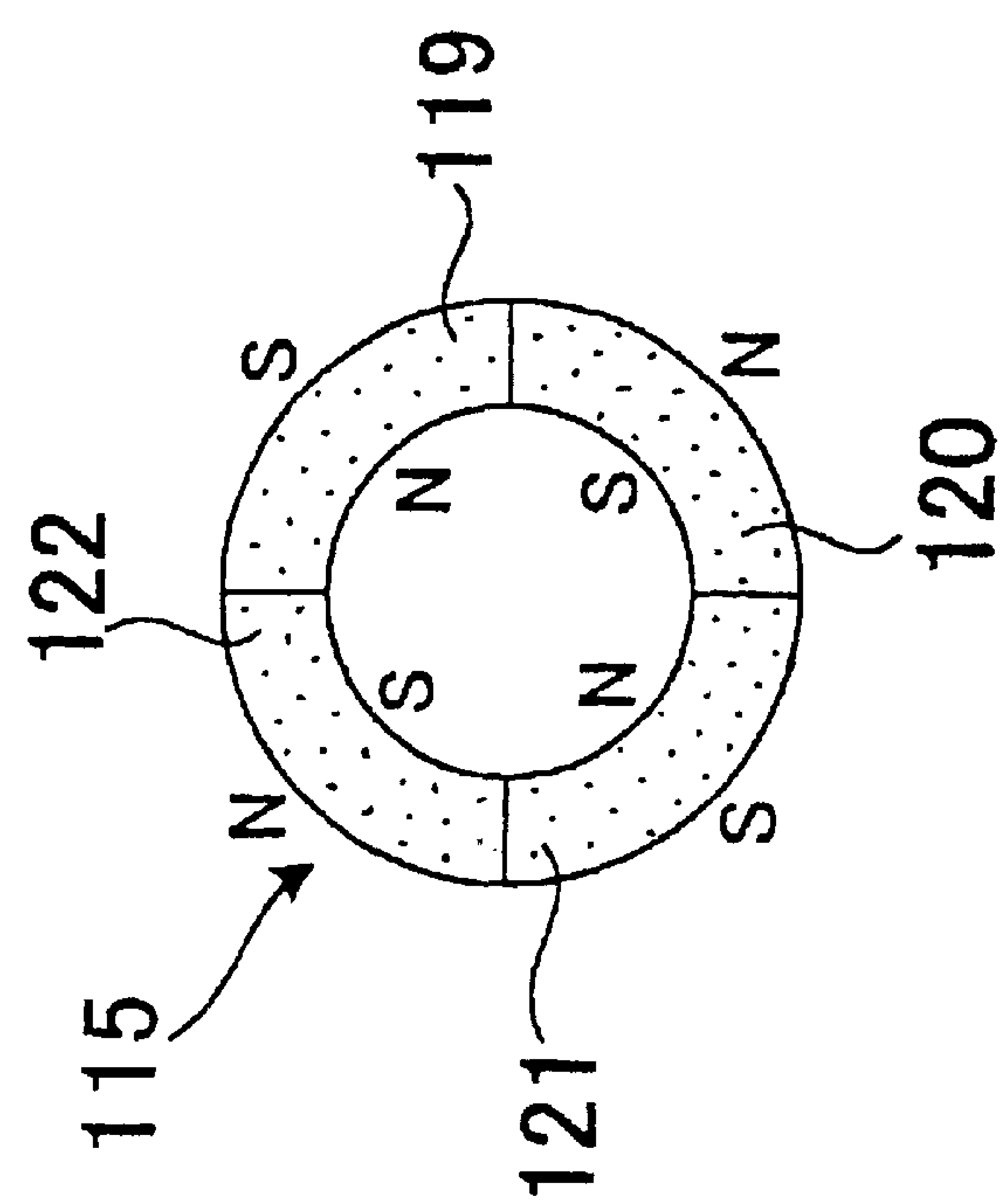
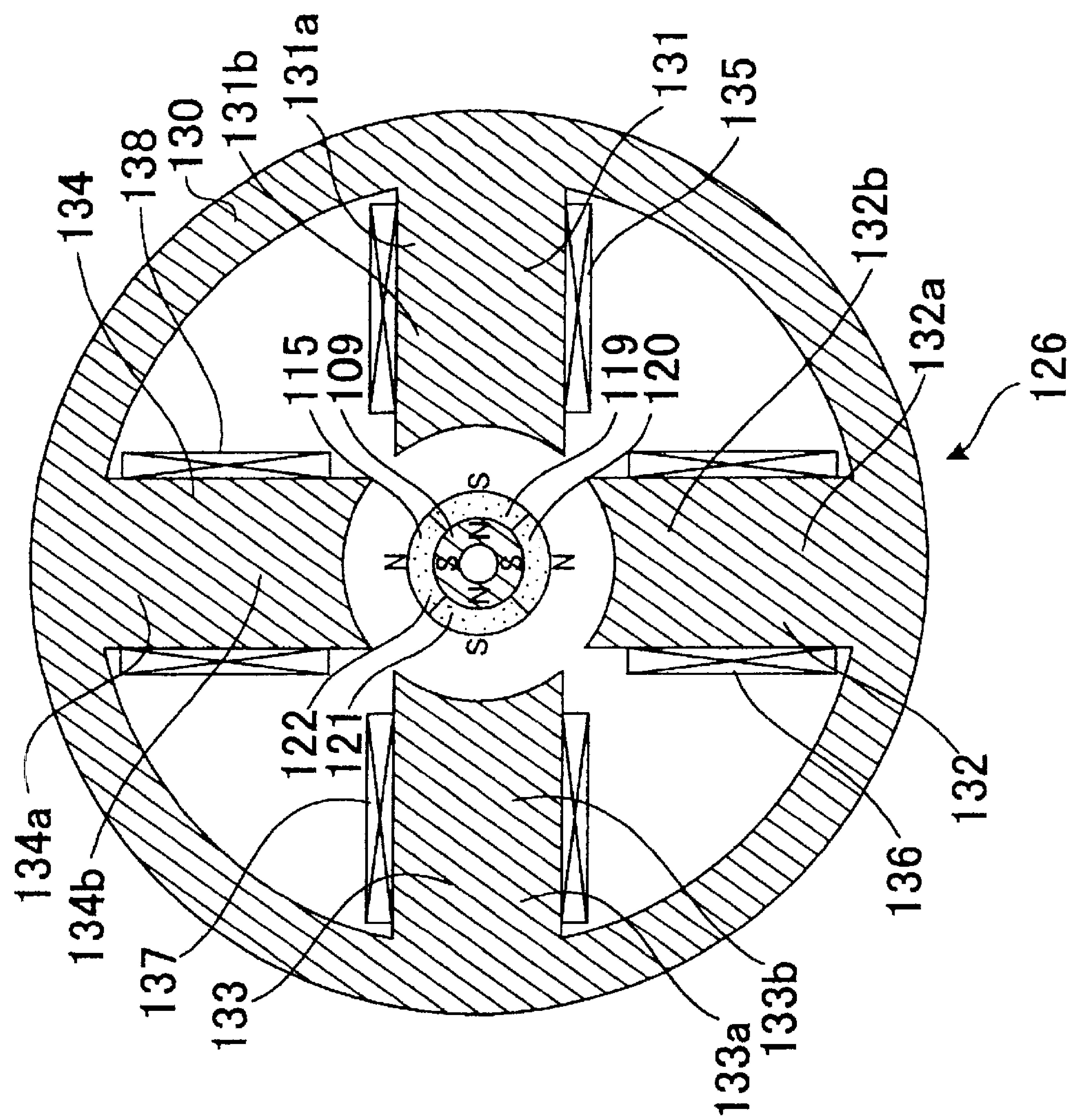


FIG. 4B


131a
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133b
136
132
N
S
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S

FIG. 4A

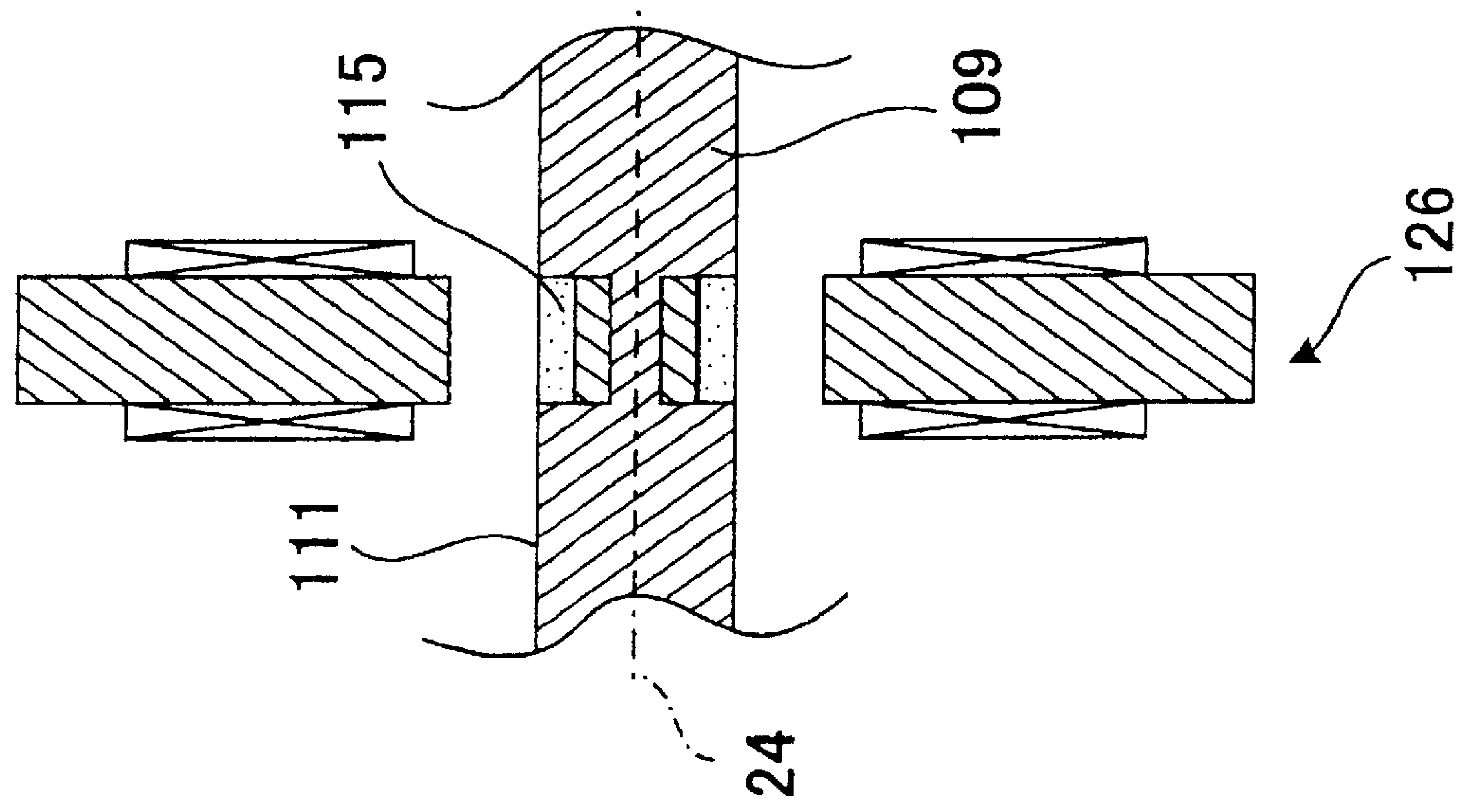
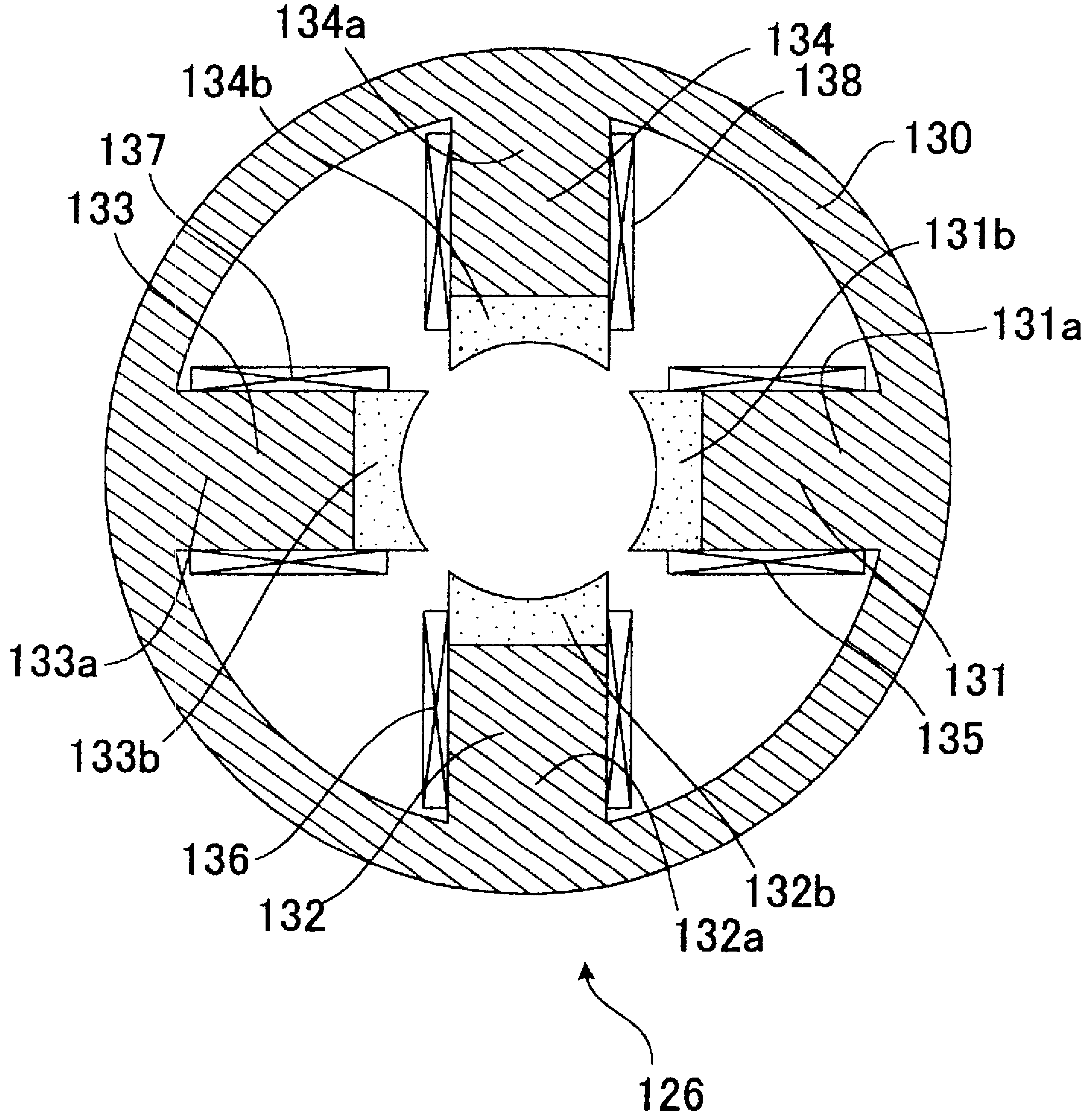

115
109
126
111
124

FIG. 5


134a
134
134b
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137
133
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131a
133a
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135
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136
132
132b
132a
126

FIG. 6B

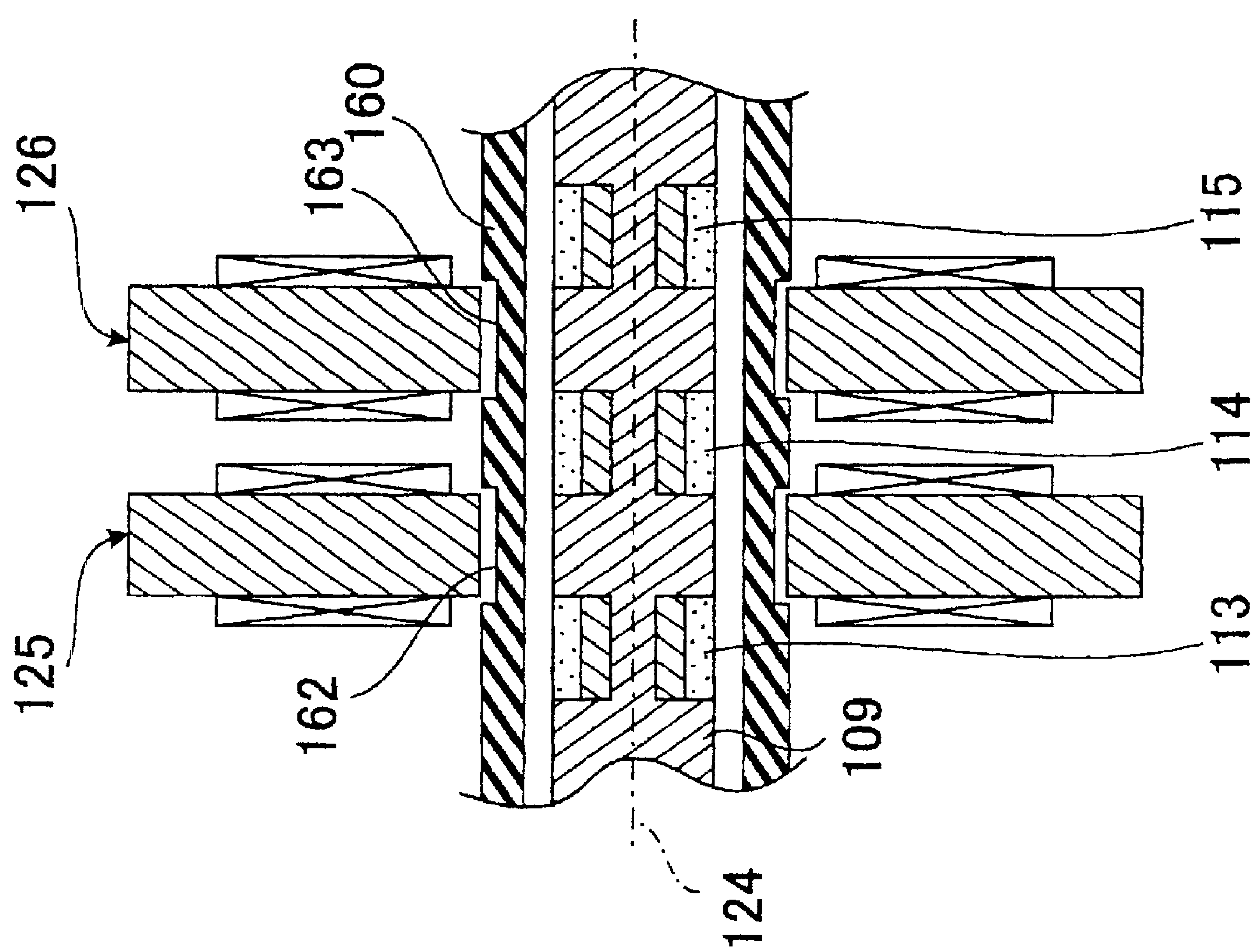


FIG. 6A

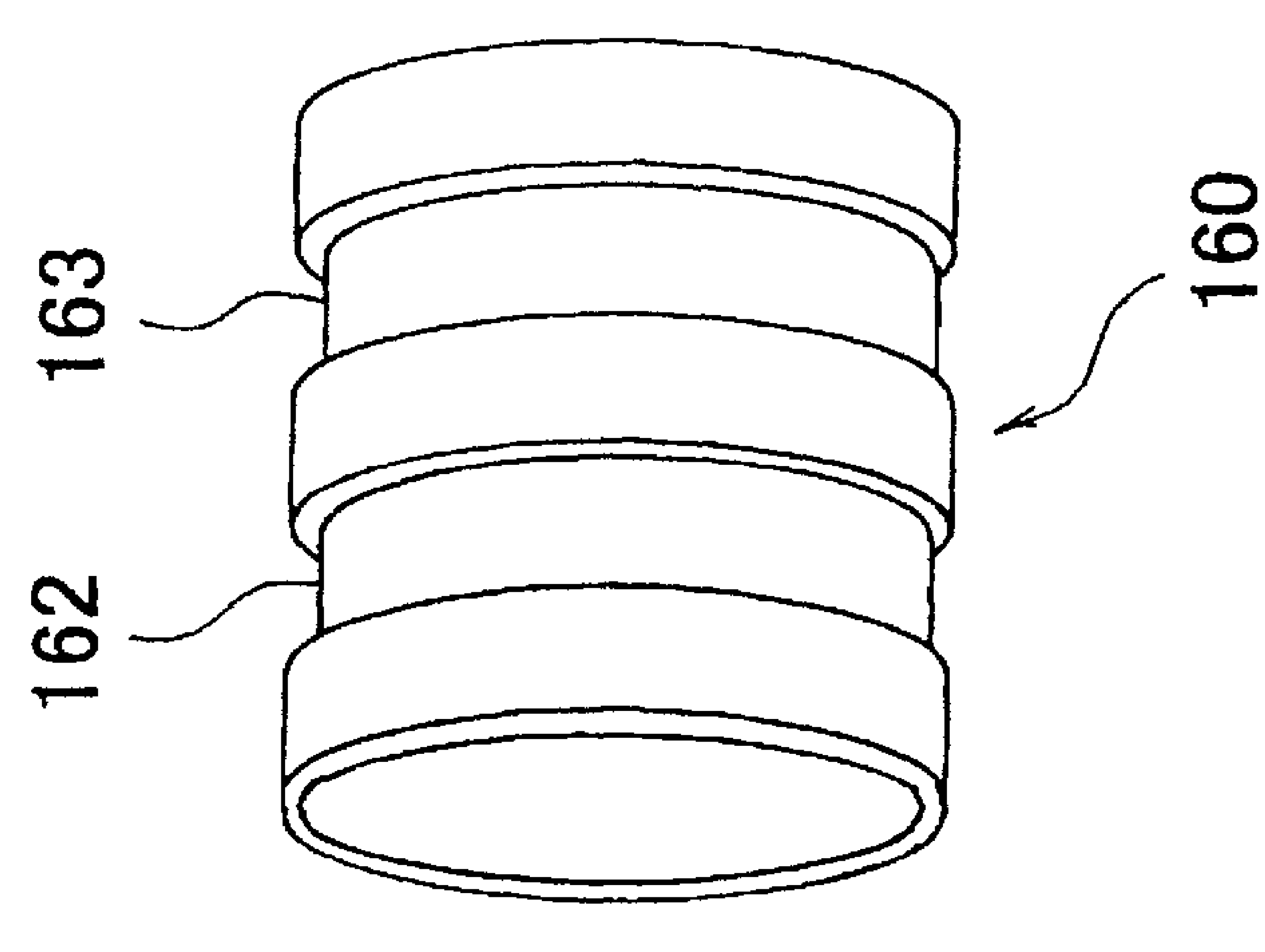
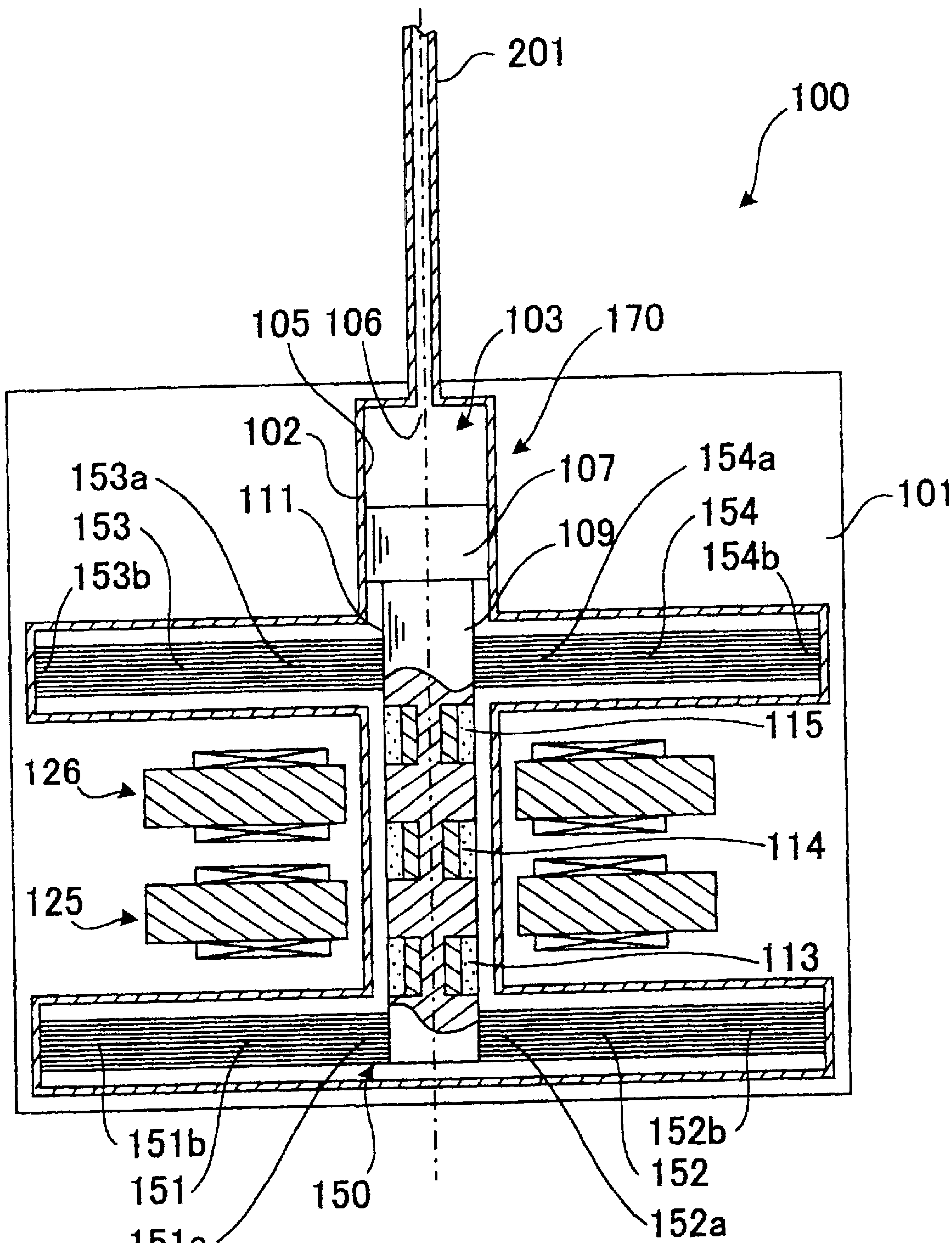


FIG. 7



201
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105 106
103
170
102
107
154a
153a
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111
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109
154
153b
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115
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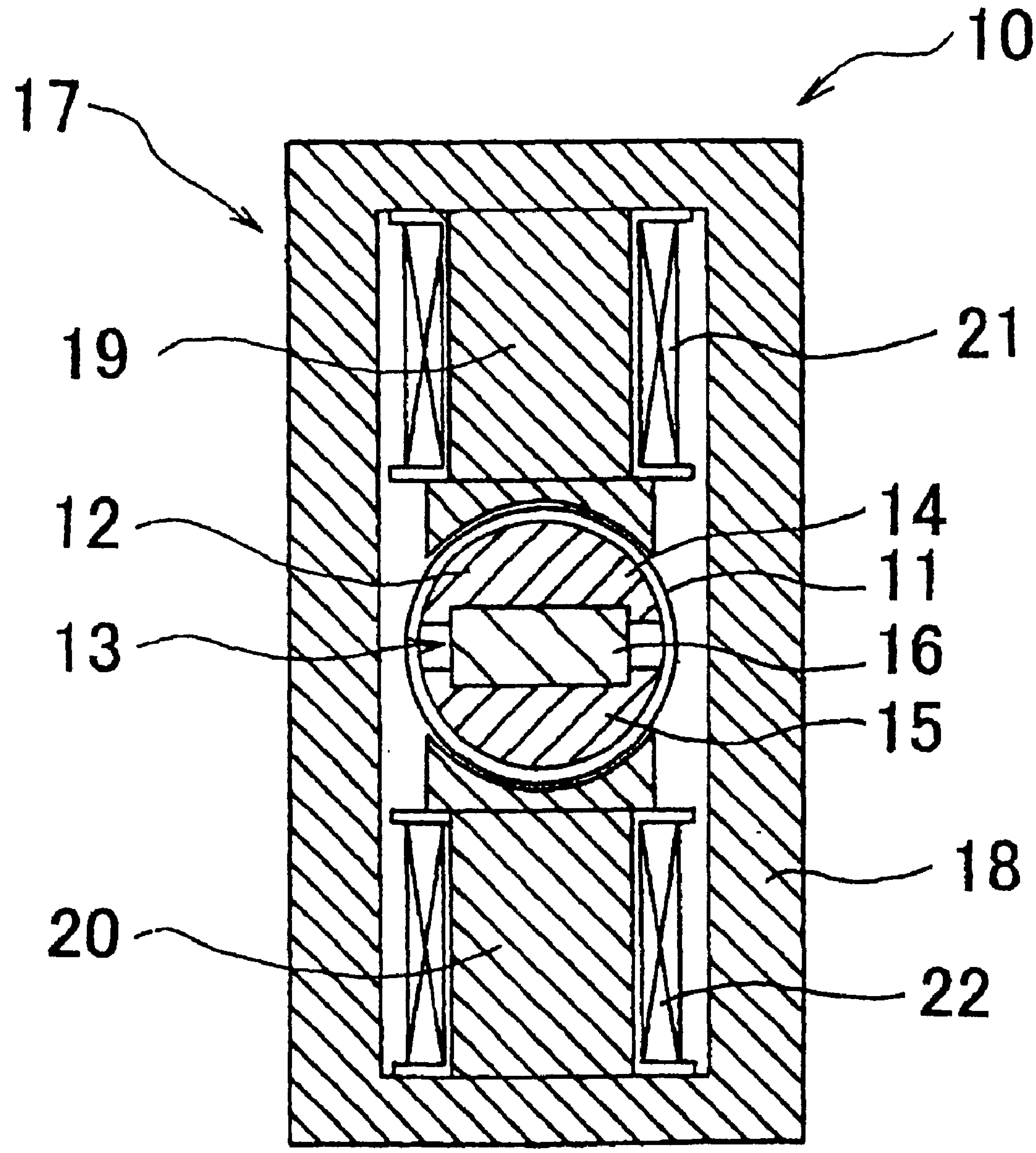
125
113
151b
152b
151
150
152
151a
152a

FIG. 8
PRIOR ART



LINEAR COMPRESSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a linear compressor and more particularly to a moving magnet type of linear compressor that is of a high efficiency and used for a cooling machine. The present invention is concerned with an improved linear compressor so constructed as to ensure that the linear compressor effectively increases a density of magnetic flux passing through an electromagnet unit to impart an increased thrust force to a piston forming part of the linear compressor.

2. Description of the Related Art

There have so far been proposed a wide variety of prior-art linear compressors one of which is exemplified and shown in FIG. **8**. The prior-art linear compressor **10** thus proposed comprises a fixed member **11** formed with a hermetically sealed compression chamber to receive a working fluid therein, a piston rod **12** slidably movably supported by the fixed member **11** and connected to the piston serving to compress the working fluid in the compression chamber, a magnet unit **13** including a plurality of yoke portions **14** and **15** accommodated in the piston rod **12** and a permanent magnet **16** in the form of a rectangular shape in cross-section and supported by the yoke portions **14** and **15** to be positioned in the center portion of the piston rod **12** and an electromagnetic unit **17** including a peripheral portion **18**, a plurality of yoke portions **19** and **20** radially inwardly extending from the peripheral portion **18** and a plurality of magnetic coils **21** and **22** each wound around each of the yoke portions **19** and **20**. The permanent magnet **16** of the magnet unit **13** is arranged in face-to-face relationship with the yoke portions **19** and **20** of the electromagnet units **17** in the longitudinal direction of the piston rod **12**.

The prior-art linear compressor thus constructed encounters such a problem as failing to effectively increase the density of magnetic flux passing through the yoke portions **19** and **20** of the electromagnet units **17** by the reason that the permanent magnet **16** of the magnet unit **13** is embedded in the center portion of the piston rod **12** as shown in FIG. **8**. The failure in effective increase of the density of magnetic flux makes it almost impossible to impart an increased thrust force to the piston forming part of the linear compressor.

SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide a linear compressor that can effectively increase the density of magnetic flux passing through the electromagnet unit to impart an increased thrust force to the piston forming part of the linear compressor.

It is another object of the present invention to provide a linear compressor that can increase the operating efficiency.

It is a further object of the present invention to provide a linear compressor that can be reduced in size.

It is a still further object of the present invention to provide a linear compressor that can reduce the electric consumption.

It is a yet still further object of the present invention to provide a linear compressor that can reduce the electric heat value.

In accordance with a first aspect of the present invention, there is provided a linear compressor, comprising: a retaining member; a fixed member supported by the retaining

member and formed with a hermetically sealed compression chamber to receive a working fluid therein, the fixed member having a longitudinally central portion formed with a inlet-outlet port having the working fluid introduced therein and discharged therefrom; a pair of pistons axially movably received in the compression chamber to assume respective compression positions where the working fluid is compressed in and discharged out of the compression chamber through the inlet-outlet port and respective retraction positions where the working fluid is expanded and introduced in the compression chamber through the inlet-outlet port; a pair of piston rods each having an outer peripheral portion and slidably movably supported by the fixed member, the piston rods respectively connected to the pistons to have the pistons axially move in the compression chamber, each of the piston rods made of a ferromagnetic material; a plurality of magnet units mounted on each of the outer peripheral portions of the piston rods, each of the magnet units having a plurality of magnet segments each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole; a plurality of electromagnet units supported by the retaining member to be axially spaced apart from each other in predetermined relationship with the magnet units, respectively; and resilient means for resiliently urging the piston rods to cause the piston rods to assume respective neutral positions between the compression positions and the retraction positions.

Each of the electromagnet units may include a peripheral portion, a plurality of yoke portions radially inwardly extending from the peripheral portion and integrally formed with the peripheral portion, the yoke portions being circumferentially equally spaced apart from each other, and a plurality of magnetic coils each wound around each of the yoke portions.

Each of the yoke portions of electromagnet units may have an axial length substantially equal to that of each of the magnet units.

The magnet units may include neighboring two magnet units having respective center planes each perpendicular to the center axis of each of the piston rods, and the yoke portions of the electromagnet units have respective center planes each perpendicular to the center axis of each of the piston rods, each of the center planes of the yoke portions of the electromagnet units being positioned between the center planes of the neighboring two magnet units when the piston rods assume their respective neutral positions.

Each of the yoke portions of the electromagnet units may be constituted by a plurality of piled plates each made of a ferromagnetic material and having a plane extending along the center axis of each of the piston rods.

The linear compressor may further comprise a pair of positioning members each mounted on the fixed member with respect to the magnet units, each of the positioning members formed with a plurality of annular grooves axially spaced apart from each other, each of the annular grooves functioning to facilitate positioning of each of the yoke portions of the electromagnet units with the magnet units.

Each of the yoke portions of the electromagnet units may have a radially outer end portion made of a ferromagnetic material and a radially inner end portion made of a ferromagnetic material having a saturated density of magnetic flux higher than that of the ferromagnetic material of each of the radially outer end portions of the yoke portions to ensure that the density of magnetic flux of each of the yoke portions of the electromagnet units is more increased than that of each of the yoke portions of the electromagnet units which are made of the same ferromagnetic materials.

The ferromagnetic material of each of the radially inner end portions may be made of Permendur.

Each of the magnet segments of the magnet units may be constituted by a plurality of piled plates each made of a permanent magnet and having a plane extending perpendicular to the center axis of each of the piston rods.

The resilient means may include a plurality of resilient members disposed along each of the piston rods, each of the resilient members constituted by a plurality of leaf springs each having a plane extending perpendicular to the center axis of each of the piston rods, each of the resilient members having a inner end portion fixedly connected to each of the piston rods and a outer end portion fixedly connected to the fixed member to ensure that each of the piston rods is resiliently urged and restored to the respective neutral positions when each of the piston rods is axially moved to the compression positions and the retraction positions.

The fixed member may have an inner peripheral portion held in sliding engagement with the pistons and made of a material substantially equal in thermal expansion coefficient to the material of each of the pistons.

The pair of pistons and the pair of piston rods may be located in symmetrical relationship with each other with respect to the inlet-outlet port.

The resilient members may be located in symmetrical relationship with each other with respect to the inlet-outlet port.

The working fluid may be made of a gas selected from the group consisting of helium, nitrogen, hydrogen, and neon-argon.

The permanent magnet of each of the magnet segments may be made of a ferroalloy containing nickel.

In accordance with a second aspect of the present invention, there is provided a linear compressor, comprising: a retaining member, a fixed member supported by the retaining member and formed with a hermetically sealed compression chamber to receive a working fluid therein, the fixed member having a longitudinally end portion formed with a inlet-outlet port having the working fluid introduced therein and discharged therefrom; a piston axially movably received in the compression chamber to assume a compression position where the working fluid is compressed in and discharged out of the compression chamber through the inlet-outlet port and a retraction position where the working fluid is expanded and introduced in the compression chamber through the inlet-outlet port; a piston rod having an outer peripheral portion and slidably movably supported by the fixed member, the piston rod connected to the piston to have the piston axially move in the compression chamber, the piston rod made of a ferromagnetic material; a plurality of magnet units mounted on the outer peripheral portion of the piston rod, each of the magnet units having a plurality of magnet segments each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole; a plurality of electromagnet units supported by the retaining member to be axially spaced apart from each other in predetermined relationship with the magnet units, respectively; and resilient means for resiliently urging the piston rod to cause the piston rod to assume neutral position between the compression position and the retraction position.

Each of the electromagnet units may include a peripheral portion, a plurality of yoke portions radially inwardly extending from the peripheral portion and integrally formed with the peripheral portion, the yoke portions being circumferentially equally spaced apart from each other, and a plurality of magnetic coils each wound around each of the yoke portions.

Each of the yoke portions of electromagnet units may have an axial length substantially equal to that of each of the magnet units.

The magnet units may include neighboring two magnet units having respective center planes each perpendicular to the center axis of the piston rod, and the yoke portions of the electromagnet units have respective center planes each perpendicular to the center axis of the piston rod, each of the center planes of the yoke portions of the electromagnet units being positioned between the center planes of the neighboring two magnet units when the piston rod assumes its neutral position.

Each of the yoke portions of the electromagnet units may be constituted by a plurality of piled plates each made of a ferromagnetic material and having a plane extending along the center axis of the piston rod.

The linear compressor may further comprise a positioning member mounted on the fixed member with respect to the magnet units, the positioning member formed with a plurality of annular grooves axially spaced apart from each other, each of the annular grooves functioning to facilitate positioning of each of the yoke portions of the electromagnet units with the magnet units.

Each of the yoke portions of the electromagnet units may have a radially outer end portion made of a ferromagnetic material and a radially inner end portion made of a ferromagnetic material having a saturated density of magnetic flux higher than that of the ferromagnetic material of each of the radially outer end portions of the yoke portions to ensure that the density of magnetic flux of each of the yoke portions of the electromagnet units is more increased than that of each of the yoke portions of the electromagnet units which are made of the same ferromagnetic materials.

The ferromagnetic material of each of the radially inner end portions may be made of Permendur.

Each of the magnet segments of the magnet units may be constituted by a plurality of piled plates each made of a permanent magnet and having a plane extending perpendicular to the center axis of the piston rod.

The resilient means may include a plurality of resilient members disposed along the piston rod, each of the resilient members constituted by a plurality of leaf springs each having a plane extending perpendicular to the center axis of the piston rod, each of the resilient members having a inner end portion fixedly connected to the piston rod and a outer end portion fixedly connected to the fixed member to ensure that the piston rod is resiliently urged and restored to the neutral position when the piston rod is axially moved to the compression position and the retraction position.

The fixed member may have an inner peripheral portion held in sliding engagement with the piston and made of a material substantially equal in thermal expansion coefficient to the material of the piston.

The working fluid may be made of a gas selected from the group consisting of helium, nitrogen, hydrogen, and neon-argon.

The permanent magnet of each of the magnet segments may be made of a ferroalloy containing nickel.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of a linear compressor according to the present invention will more clearly be understood from the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a cross-sectional view of the first embodiment of the linear compressor according to the present invention in combination with the pulse tube type cooling machine;

FIG. **2** is an enlarged cross-sectional view of the linear compressor shown in FIG. **1**;

FIG. **3**A is an enlarged cross-sectional view of the magnet unit;

FIG. **3**B is a view of a model for explaining the magnetic pole of the magnet unit shown in FIG. **3**A;

FIG. **3**C is a perspective view of the magnet segment of the magnet unit;

FIG. **4**A is an enlarged fragmentary cross-sectional view taken along the lines A–A' of FIG. **1**;

FIG. **4**B is an enlarged cross-sectional view taken along the lines A–A' of FIG. **1**;

FIG. **5** is a view similar to FIG. **4**B but particularly showing the yoke portions each having a radially inner end portion made of a ferromagnetic material;

FIG. **6**A is a perspective view of the positioning member of the linear compressor according to the present invention;

FIG. **6**B is a cross-sectional view of the positioning member shown in FIG. **6**A;

FIG. **7** is an enlarged cross-sectional view of the second embodiment of the linear compressor according to the present invention; and

FIG. **8** is an enlarged cross-sectional view of the prior-art linear compressor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The first preferred embodiment of a linear compressor according to the present invention will now be described in detail in accordance with the accompanying drawings.

Referring now to the drawings, particularly to FIGS. **1** to **6**, here are shown the first preferred embodiment of a linear compressor **100** according to the present invention and a pulse tube type cooling machine **200** operatively connected to the linear compressor **100**. The linear compressor **100** comprises a retaining member **101**, a fixed member **102** in the form of a cylindrical shape and supported by the retaining member **101** and formed with a hermetically sealed compression chamber **103** in the form of a cylinder shape to receive a working fluid therein. The fixed member **102** has a longitudinally central portion **104** and an inner peripheral portion **105**. The longitudinally central portion **104** of the fixed member **102** is formed with a inlet-outlet port **106** having the working fluid introduced therein and discharged therefrom. The working fluid is made of a gas selected from the group consisting of helium, nitrogen, hydrogen, and neon-argon.

The linear compressor **100** further comprises a pair of pistons **107** and **108** each in the form of a cylinder shape and axially movably received in the compression chamber **103** to assume respective compression positions where the working fluid is compressed in and discharged out of the compression chamber **103** through the in-let-outlet port **106** and respective retraction positions where the working fluid is expanded and introduced in the compression chamber **103** through the inlet-outlet port **106**. The inner peripheral portion **105** of the fixed member **102** is held in sliding engagement with the pistons **107** and **108** and made of a material substantially equal in thermal expansion coefficient to the material of each of the pistons **107** and **108**.

The linear compressor **100** further comprises a pair of piston rods **109** and **110** each having an outer peripheral portion **111** and **112**. The piston rods **109** and **110** are slidably movably supported by the fixed member **102** and respectively connected to the pistons **107** and **108** to have the pistons **107** and **108** axially move in the compression chamber **103**. Each of the piston rods **109** and **110** is in the form of a cylinder shape and made of a ferromagnetic material. The pair of pistons **107** and **108** and the pair of piston rods **109** and **110** are located in symmetrical relationship with each other with respect to the inlet-outlet port **106**.

The linear compressor **100** further comprises a plurality of magnet units **113** to **118** each in the form of an annular ring shape and mounted on each of the outer peripheral portions **111** and **112** of the piston rods **109** and **110** to be axially spaced apart from each other. The cross-section of the magnet unit **115** is shown in FIGS. **3**A, **3**B and **3**C to have a plurality of magnet segments **119** to **122** each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole. Each of the magnet segments **119** to **122** of the magnet unit **115** is constituted by a plurality of piled plates **123** each made of a permanent magnet and having a plane extending perpendicular to the center axis **124** of each of the piston rods **109** and **110**. The permanent magnet of each of the magnet segments **119** to **122** of the magnet unit **115** is made of a ferroalloy containing nickel.

While it has been described about the above embodiment that the linear compressor **100** comprises a plurality of magnet units **113** to **118** mounted on each of the outer peripheral portions **111** and **112** of the piston rods **109** and **110** to be axially spaced apart from each other, the magnet units **113** to **118** may be mounted on each of the outer peripheral portions **111** and **112** of the piston rods **109** and **110** in face-to-face contact with each other in the axial direction of the piston rods **109** and **110** according to the present invention. This means that the side surfaces of the magnet units **113** to **118** may be held in abutting engagement with each other.

The cross-section of the magnet units **113, 114, 116, 117, 118** are not shown in FIGS. **3**A, **3**B and **3**C but entirely the same as the cross-section of the magnet unit **115**. It will thus be understood that the constructions of the magnet units **113, 114, 116, 117, 118** are entirely the same as that of the magnet unit **115**. The constructions of the magnet units **113,114,116, 117,118** will therefore not be described hereinafter.

The linear compressor **100** further comprises a plurality of electromagnet units **125** to **128** supported by the retaining member **101** to be axially spaced apart from each other in predetermined relationship with the magnet units **113** to **118,** respectively. The cross-section of the electromagnet unit **126** is shown in FIGS. **4**A, **4**B and **5** to include a peripheral portion **130** in the form of an annular ring shape, a plurality of yoke portions **131** to **134**, and a plurality of magnetic coils **135** to **138**. The yoke portions **131** to **134** of the electromagnet unit **126** radially inwardly extend from the peripheral portion **130**. The yoke portions **131** to **134** of the electromagnet unit **126** are integrally formed with the peripheral portion **130** and circumferentially equally spaced apart from each other. The magnetic coils **135** to **138** of the electromagnet unit **126** are each wound around each of the yoke portions **131** to **134** and controlled by a controller **139** to be actuated alternately in magnet pole.

Each of the yoke portions **131** to **134** of the electromagnet unit **126** has an axial length substantially equal to that of each of the magnet units **113** to **118**. Each of the yoke portions **131** to **134** of the electromagnet unit **126** is constituted by a plurality of piled plates each made of a ferromagnetic material and having a plane extending along the center axis **124** of each of the piston rods **109** and **110**.

In FIG. **5**, each of the yoke portions **131** to **134** of the electromagnet unit **126** has a radially outer end portion **131***a* to **134***a* made of a ferromagnetic material and a radially inner end portion **131***b* to **134***b* made of a ferromagnetic material having a saturated density of magnetic flux higher than that of the ferromagnetic material of each of the radially outer end portions **131***a* to **134***a* of the yoke portions **131** to **134** to ensure that the density of magnetic flux of each of the yoke portions **131** to **134** of the electromagnet unit **126** is more increased than that of each of the yoke portions **131** to **134** of the electromagnet unit **126** which are made of the same ferromagnetic materials. The ferromagnetic material of each of the radially inner end portions **131***b* to **134***b* of the yoke portions **131** to **134** is made of Permendur.

The cross-sections of the electromagnet units **125, 127** and **128** are not shown in FIGS. **4**A, **4**B, and **5** but entirely the same as the cross-section of the electromagnet unit **126**. It will thus be understood that the constructions of the electromagnet units **125, 127** and **128** are entirely the same as that of the electromagnet unit **126**. The constructions of the electromagnet units **125, 127** and **128** will therefore not be described hereinafter.

The magnet units **113** to **118** include neighboring two magnet units having respective center planes each perpendicular to the center axis **124** of each of the piston rods **109** and **110**. The yoke portions **131** to **134** of the electromagnet units **125** to **128** have respective center planes each perpendicular to the center axis **124** of each of the piston rods **109** and **110**. Each of the center planes of the yoke portions **131** to **134** of the electromagnet units **125** to **128** are positioned between the center planes of the neighboring two magnet units when the piston rods **109** and **110** assume their respective neutral positions.

The linear compressor **100** further comprises resilient means **150** for resiliently urging the piston rods **109** and **110** to cause the piston rods **109** and **110** to assume respective neutral positions between the compression positions and the retraction positions. The resilient means **150** includes a plurality of resilient members **151** to **158** disposed along each of the piston rods **109** and **110**. Each of the resilient members **151** to **158** are constituted by a plurality of leaf springs each having a plane extending perpendicular to the center axis **124** of each of the piston rods **109** and **110**. Each of the resilient members **151** to **158** has a inner end portion **151***a* to **158***a* fixedly connected to each of the piston rods **109** and **110** and a outer end portion **151***b* to **158***b* fixedly connected to the fixed member **102** to ensure that each of the piston rods **109** and **110** is resiliently urged and restored to the respective neutral positions when each of the piston rods **109** and **110** is axially moved to the compression positions and the retraction positions. The resilient members **151** to **158** are located in symmetrical relationship with each other with respect to the inlet-outlet port **106**.

The linear compressor **100** further comprises a pair of positioning members **160** and **161** each in the form of a cylinder shape and mounted on the fixed member **102** with respect to the magnet units **113** to **118**. The cross-section of the positioning member **160** is shown in FIGS. **6**A and **6**B to be formed with a plurality of annular grooves **162** and **163** axially spaced apart from each other. Each of the annular grooves **162** and **163** of the positioning member **160** functions to facilitate positioning of each of the yoke portions **131** to **134** of the electromagnet units **125** and **126** with the magnet units **113** to **115**.

The cross-section of the positioning member **161** is not shown in FIGS. **6**A and **6**B but entirely the same as the cross-section of the positioning member **160**. It will thus be understood that the constructions of the positioning member **161** is entirely the same as that of the positioning member **160**. The constructions of the positioning member **161** will therefore not be described hereinafter.

The pulse tube type cooling machine **200** is operatively connected to the linear compressor **100**. The pulse tube type cooling machine **200** includes a connecting pipe **201** having a passageway formed therein and connected at one end to the fixed member **102** with the passageway held in communication with the inlet-outlet port **106** of the fixed member **102**, a heat accumulator **202** having one end connected to the other end of the connecting pipe **201** to accumulate the working fluid fed through the passageway of the connecting pipe **201** from the compression chamber **103** of the fixed member **102** and the other end through which the working fluid is discharged, a pulse tube **203** having one end connected to the other end of the heat accumulator **202** to discharge heat therefrom, a buffer tank **204** connected to the other end of the pulse tube **203** by way of a connecting pipe **205** having a portion bifurcated and having a pair of check valves **206** and **207** therein to allow the working fluid to be checked, a change-over valve **208** provided on a connecting pipe **209** and controlled by a controller **139** on whether the change-over valve **208** is opened or closed.

As will be understood form the forgoing description, the magnet units are mounted on each of the outer peripheral portions of the piston rods to be axially spaced apart from each other, the electromagnet units are supported by the retaining member to be axially spaced apart from each other in predetermined relationship with the magnet units respectively, each of the magnet segments of the magnet units is constituted by a plurality of piled plates and having a plane extending perpendicular to the center axis of each of the piston rods, and each of the yoke portions of the electromagnet units is constituted by a plurality of piled plates and having a plane extending along the center axis of each of the piston rods.

The liner compressor thus constructed in the above makes it possible (1) to increase the density of magnetic flux passing through the electromagnet unit to impart an increased thrust force to the piston forming part of the linear compressor, (2) to increase the operating efficiency, (3) to be reduced in size, (4) to reduce the electric consumption, (5) to reduce the electric heat value, and (6) to reduce eddy currents in the electromagnet unit.

While it has been described in the first embodiment of the linear compressor according to the present invention, the fixed member **102**, the pistons **107** and **108**, the piston rods **109** and **110**, and the positioning members **160** and **161** are each in the form of a cylindrical shape, the fixed member **102**, the pistons **107** and **108**, the piston rods **109** and **110**, and the positioning members **160** and **161** may be each in the form of a polygonal shape such as triangular, square and rectangular shape in cross-section.

While the linear compressor **100** has been described in the above as comprising the pair of piston rods **109** and **110** respectively connected to the pistons **107** and **108** to have the pistons **107** and **108** axially move in the compression chamber **103** as shown in FIG. **2**, the linear compressor **100** may be replaced by a linear compressor comprising a single piston rod connected to a single piston to have the single piston axially move in a compression chamber according to the present invention.

The second embodiment directed to the linear compressor comprising the single piston rod connected to the single piston to have the single piston axially move in the compression chamber is shown in FIG. 7.

In FIG. 7, the linear compressor **100** comprises a retaining member **101**, a fixed member **102** supported by the retaining member **101** and formed with a hermetically sealed compression chamber **103** in the form of a cylinder shape to receive a working fluid therein. The fixed member **102** has a longitudinally end portion **170** and an inner peripheral portion **105**. The longitudinally end portion **170** of the fixed member **102** is formed with a inlet-outlet port **106** having the working fluid introduced therein and discharged therefrom.

The linear compressor **100** further comprises a piston **107** axially movably received in the compression chamber **103** to assume compression position where the working fluid is compressed in and discharged out of the compression chamber **103** through the inlet-outlet port **106** and retraction position where the working fluid is expanded and introduced in the compression chamber **103** through the inlet-outlet port **106**. The inner peripheral portion **105** of the fixed member **102** is held in sliding engagement with the piston **107** and made of a material substantially equal in thermal expansion coefficient to the material of each of the piston **107**.

The linear compressor **100** further comprises a piston rod **109** having an outer peripheral portion **111**. The piston rod **109** is slidably movably supported by the fixed member **102** and connected to the piston **107** to have the piston **107** axially move in the compression chamber **103**.

The linear compressor **100** further comprises a plurality of magnet units **113** to **115** each being in the form of an annular ring shape and mounted on the outer peripheral portion **111** of the piston rod **109** to be axially spaced apart from each other.

The linear compressor **100** further comprises a plurality of electromagnet units **125** and **126** supported by the retaining member **101** to be axially spaced apart from each other in predetermined relationship with the magnet units **113** to **115**, respectively.

The linear compressor **100** farther comprises resilient means **150** for resiliently urging the piston rod **109** to cause the piston rod **109** to assume neutral position between the compression position and the retraction position. The resilient means **150** includes a plurality of resilient members **151** to **154** disposed along the piston rod **109**. Each of the resilient members **151** to **154** has a inner end portion **151***a* to **154***a* fixedly connected to the piston rod **109** and a outer end portion **151***b* to **154***b* fixedly connected to the fixed member **102** to ensure that the piston rod **109** is resiliently urged and restored to the neutral position when the piston rod **109** is axially moved to the compression position and the retraction position.

It is understood that the second embodiment of the linear compressor has an advantage and effect the same as that of the first embodiment of the linear compressor.

What is claimed is:

1. A linear compressor, comprising:

a retaining member;

a fixed member supported by said retaining member and formed with a hermetically sealed compression chamber to receive a working fluid therein, said fixed member having a longitudinally central portion formed with a inlet-outlet port having said working fluid introduced therein and discharged therefrom;

a pair of pistons axially movably received in said compression chamber to assume respective compression positions where said working fluid is compressed in and discharged out of said compression chamber through said inlet-outlet port and respective retraction positions where said working fluid is expanded and introduced in said compression chamber through said inlet-outlet port;

a pair of piston rods each having an outer peripheral portion and slidably movably supported by said fixed member, said piston rods respectively connected to said pistons to have said pistons axially move in said compression chamber, each of said piston rods made of a ferromagnetic material;

a plurality of magnet units mounted on each of said outer peripheral portions of said piston rods, each of said magnet units having a plurality of magnet segments each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole;

a plurality of electromagnet units supported by said retaining member to be axially spaced apart from each other in predetermined relationship with said magnet units, respectively; and

resilient means for resiliently urging said piston rods to cause said piston rods to assume respective neutral positions between said compression positions and said retraction positions.

2. A linear compressor as set forth in claim 1, in which each of said electromagnet units includes a peripheral portion, a plurality of yoke portions radially inwardly extending from said peripheral portion and integrally formed with said peripheral portion, said yoke portions being circumferentially equally spaced apart from each other, and a plurality of magnetic coils each wound around each of said yoke portions.

3. A linear compressor as set forth in claim 2, in which each of said yoke portions of electromagnet units has an axial length substantially equal to that of each of said magnet units.

4. A linear compressor as set forth in claim 2, in which said magnet units include neighboring two magnet units having respective center planes each perpendicular to the center axis of each of said piston rods, and said yoke portions of said electromagnet units have respective center planes each perpendicular to the center axis of each of said piston rods, each of said center planes of said yoke portions of said electromagnet units being positioned between said center planes of said neighboring two magnet units when said piston rods assume their respective neutral positions.

5. A linear compressor as set forth in claim 2, in which each of said yoke portions of said electromagnet units is constituted by a plurality of piled plates each made of a ferromagnetic material and having a plane extending along the center axis of each of said piston rods.

6. A linear compressor as set forth in claim 2, which further comprises a pair of positioning members each mounted on said fixed member with respect to said magnet units, each of said positioning members formed with a plurality of annular grooves axially spaced apart from each other, each of said annular grooves functioning to facilitate positioning of each of said yoke portions of said electromagnet units with said magnet units.

7. A linear compressor as set forth in claim 2, in which each of said yoke portions of said electromagnet units has a radially outer end portion made of a ferromagnetic material and a radially inner end portion made of a ferromagnetic material having a saturated density of magnetic flux higher than that of said ferromagnetic material of each of said radially outer end portions of said yoke portions to ensure

that the density of magnetic flux of each of said yoke portions of said electromagnet units is more increased than that of each of said yoke portions of said electromagnet units which are made of the same ferromagnetic materials.

8. A linear compressor as set forth in claim **7**, in which said ferromagnetic material of each of said radially inner end portions is made of Permendur.

9. A linear compressor as set forth in claim **1**, in which each of said magnet segments of said magnet units is constituted by a plurality of piled plates each made of a permanent magnet and having a plane extending perpendicular to the center axis of each of said piston rods.

10. A linear compressor as set forth in claim **1**, in which said resilient means includes a plurality of resilient members disposed along each of said piston rods, each of said resilient members constituted by a plurality of leaf springs each having a plane extending perpendicular to the center axis of each of said piston rods, each of said resilient members having a inner end portion fixedly connected to each of said piston rods and a outer end portion fixedly connected to said fixed member to ensure that each of said piston rods is resiliently urged and restored to said respective neutral positions when each of said piston rods is axially moved to said compression positions and said retraction positions.

11. A linear compressor as set forth in claim **1**, in which said fixed member has an inner peripheral portion held in sliding engagement with said pistons and made of a material substantially equal in thermal expansion coefficient to the material of each of said pistons.

12. A linear compressor as set forth in claim **1**, in which said pair of pistons and said pair of piston rods are located in symmetrical relationship with each other with respect to said inlet-outlet port.

13. A linear compressor as set forth in claim **1**, in which said resilient members are located in symmetrical relationship with each other with respect to said inlet-outlet port.

14. A linear compressor as set forth in claim **1**, in which said working fluid is made of a gas selected from the group consisting of helium, nitrogen, hydrogen, and neon-argon.

15. A linear compressor as set forth in claim **1**, in which said permanent magnet of each of said magnet segments is made of a ferroalloy containing nickel.

16. A linear compressor, comprising:

a retaining member;

a fixed member supported by said retaining member and formed with a hermetically sealed compression chamber to receive a working fluid therein, said fixed member having a longitudinally end portion formed with a inlet-outlet port having said working fluid introduced therein and discharged therefrom;

a piston axially movably received in said compression chamber to assume a compression position where said working fluid is compressed in and discharged out of said compression chamber through said inlet-outlet port and a retraction position where said working fluid is expanded and introduced in said compression chamber through said inlet-outlet port;

a piston rod having an outer peripheral portion and slidably movably supported by said fixed member, said piston rod connected to said piston to have said piston axially move in said compression chamber, said piston rod made of a ferromagnetic material;

a plurality of magnet units mounted on said outer peripheral portion of said piston rod, each of said magnet units having a plurality of magnet segments each made of a permanent magnet and circumferentially arranged with neighboring two magnet segments different in magnetic pole;

a plurality of electromagnet units supported by said retaining member to be axially spaced apart from each other in predetermined relationship with said magnet units, respectively; and

resilient means for resiliently urging said piston rod to cause said piston rod to assume neutral position between said compression position and said retraction position.

17. A linear compressor as set forth in claim **16**, in which each of said electromagnet units includes a peripheral portion, a plurality of yoke portions radially inwardly extending from said peripheral portion and integrally formed with said peripheral portion, said yoke portions being circumferentially equally spaced apart from each other, and a plurality of magnetic coils each wound around each of said yoke portions.

18. A linear compressor as set forth in claim **17**, in which each of said yoke portions of electromagnet units has an axial length substantially equal to that of each of said magnet units.

19. A linear compressor as set forth in claim **17**, in which said magnet units include neighboring two magnet units having respective center planes each perpendicular to the center axis of said piston rod, and said yoke portions of said electromagnet units have respective center planes each perpendicular to the center axis of said piston rod, each of said center planes of said yoke portions of said electromagnet units being positioned between said center planes of said neighboring two magnet units when said piston rod assumes its neutral position.

20. A linear compressor as set forth in claim **17**, in which each of said yoke portions of said electromagnet units is constituted by a plurality of piled plates each made of a ferromagnetic material and having a plane extending along the center axis of said piston rod.

21. A linear compressor as set forth in claim **17**, which further comprises a positioning member mounted on said fixed member with respect to said magnet units, said positioning member formed with a plurality of annular grooves axially spaced apart from each other, each of said annular grooves functioning to facilitate positioning of each of said yoke portions of said electromagnet units with said magnet units.

22. A linear compressor as set forth in claim **17**, in which each of said yoke portions of said electromagnet units has a radially outer end portion made of a ferromagnetic material and a radially inner end portion made of a ferromagnetic material having a saturated density of magnetic flux higher than that of said ferromagnetic material of each of said radially outer end portions of said yoke portions to ensure that the density of magnetic flux of each of said yoke portions of said electromagnet units is more increased than that of each of said yoke portions of said electromagnet units which are made of the same ferromagnetic materials.

23. A linear compressor as set forth in claim **22**, in which said ferromagnetic material of each of said radially inner end portions is made of Permendur.

24. A linear compressor as set forth in claim **16**, in which each of said magnet segments of said magnet units is constituted by a plurality of piled plates each made of a permanent magnet and having a plane extending perpendicular to the center axis of said piston rod.

25. A linear compressor as set forth in claim **16**, in which said resilient means includes a plurality of resilient members disposed along said piston rod, each of said resilient members constituted by a plurality of leaf springs each having a plane extending perpendicular to the center axis of said piston rod, each of said resilient members having a inner end portion fixedly connected to said piston rod and a outer end portion fixedly connected to said fixed member to ensure that said piston rod is resiliently urged and restored to said neutral position when said piston rod is axially moved to said compression position and said retraction position.

26. A linear compressor as set forth in claim **16**, in which said fixed member has an inner peripheral portion held in sliding engagement with said piston and made of a material substantially equal in thermal expansion coefficient to the material of said piston.

27. A linear compressor as set forth in claim **16**, in which said working fluid is made of a gas selected from the group consisting of helium, nitrogen, hydrogen, and neon-argon.

28. A linear compressor as set forth in claim **16**, in which said permanent magnet of each of said magnet segments is made of a ferroalloy containing nickel.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,499,972 B2
DATED : December 31, 2002
INVENTOR(S) : Shinichi Yatsuzuka, Yasumasa Hagiwara and Keiji Takizawa

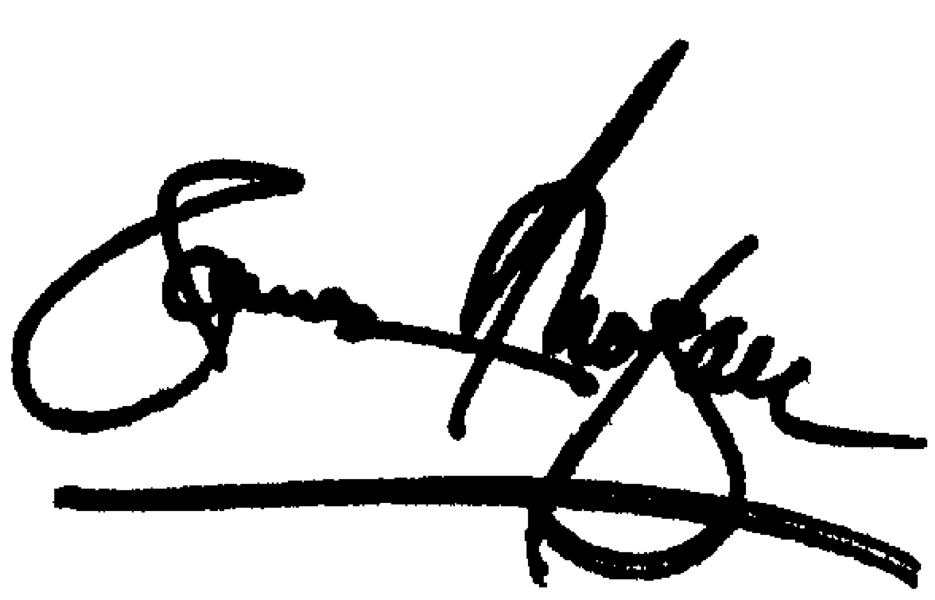
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [75], should read:

-- [75] Inventors: **Shinichi Yatsuzuka**, Aichi (JP)
Yasumasa Hagiwara, Aichi (JP)
Keiji Takizawa, Aichi (JP) --

Signed and Sealed this

Eighth Day of July, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office